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(54) **HIGH GAIN BIPOLAR TRANSISTOR**

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(52) **U.S. Cl.** ..... **257/557**; 257/561; 257/575; 257/591; 257/592; 257/593

(58) **Field of Search** ..... 257/561, 575, 257/591, 592, 593, 557, 571, 578, 579, 587, 588, 562, 563

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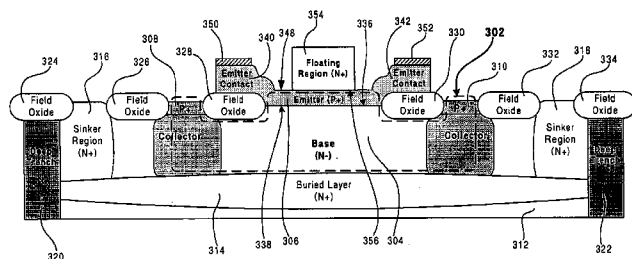
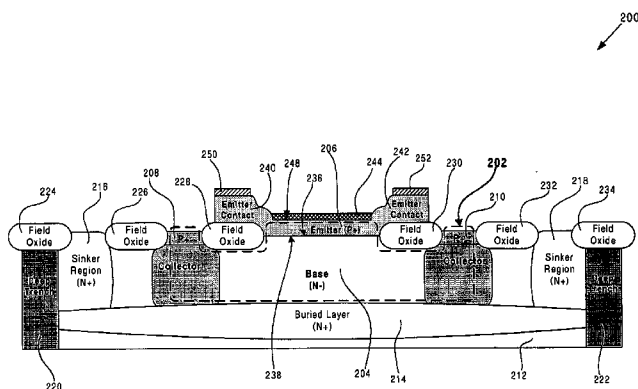
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(57) **ABSTRACT**

According to one exemplary embodiment, a bipolar transistor comprises a base having a top surface. The bipolar transistor might be a lateral PNP bipolar transistor and the base may comprise, for example, N type single crystal silicon. The bipolar transistor further comprises an emitter having a top surface, where the emitter is situated on the top surface of the base. The emitter may comprise P+ type single crystal silicon-germanium, for example. The bipolar transistor further comprises an electron barrier layer situated directly on the top surface of the emitter. The electron barrier layer will cause an increase in the gain, or beta, of the bipolar transistor. The electron barrier layer may be a dielectric such as, for example, silicon oxide. In another embodiment, a floating N+ region, instead of the electron barrier layer, is utilized to increase the gain of the bipolar transistor.

**15 Claims, 4 Drawing Sheets**



**Fig. 1**  
(Prior Art)

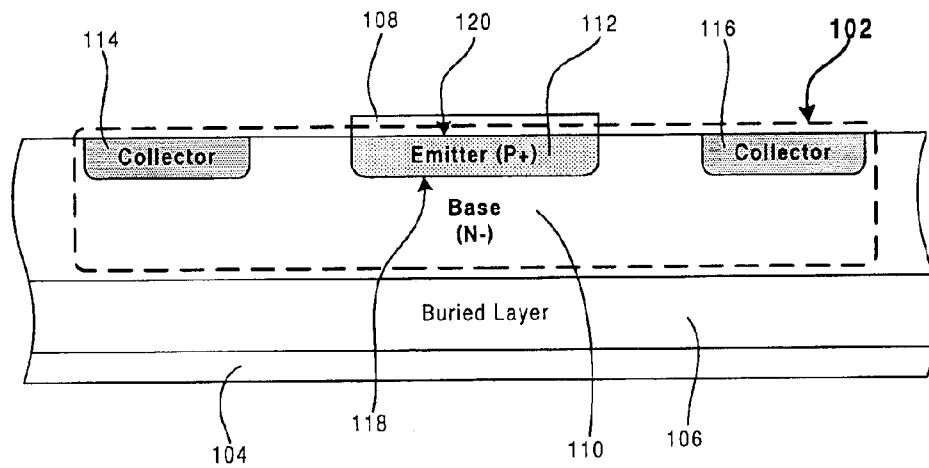
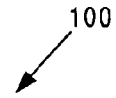


Fig. 2

200

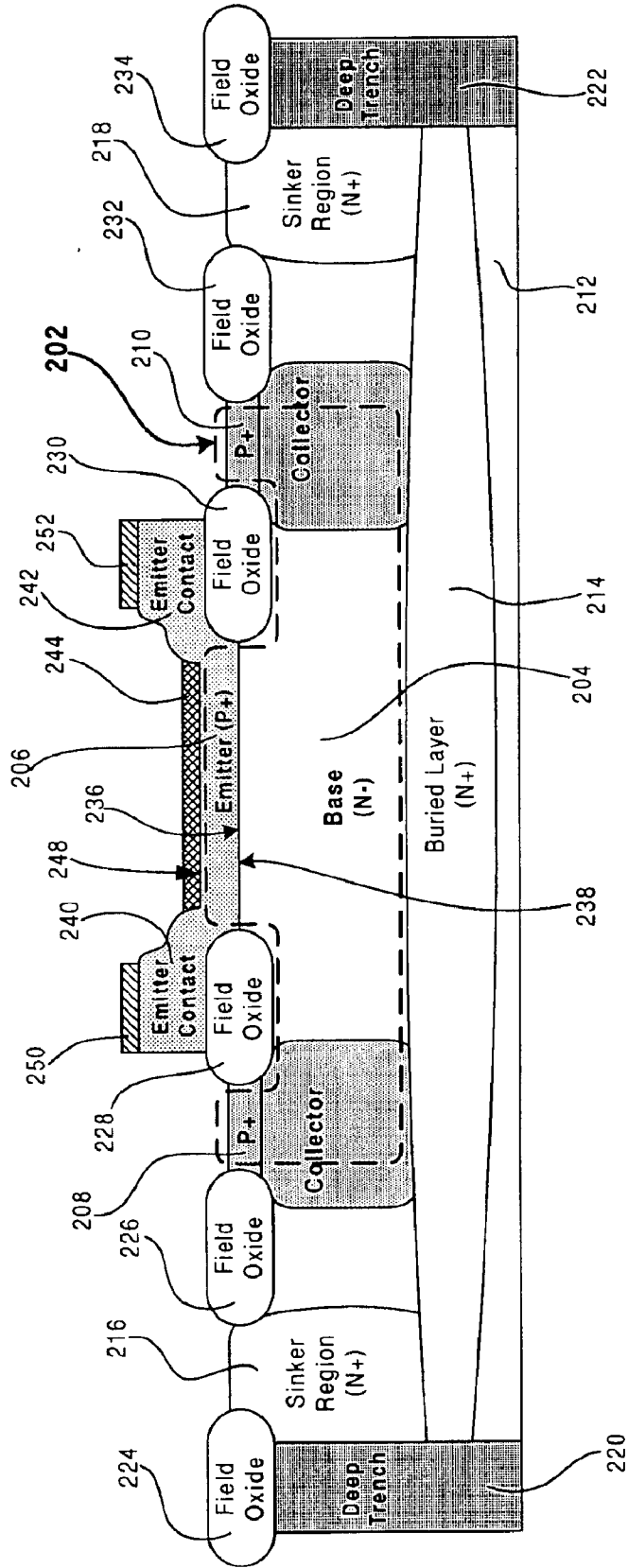


Fig. 3

300

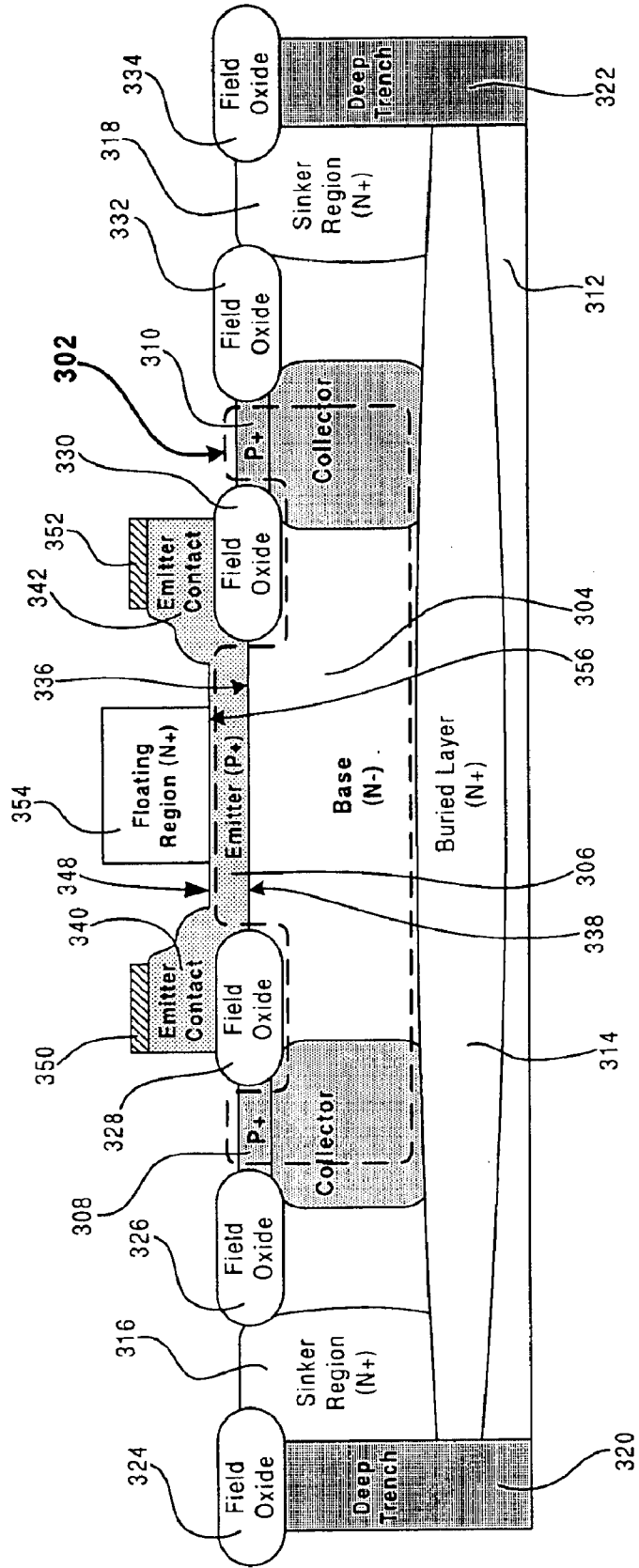
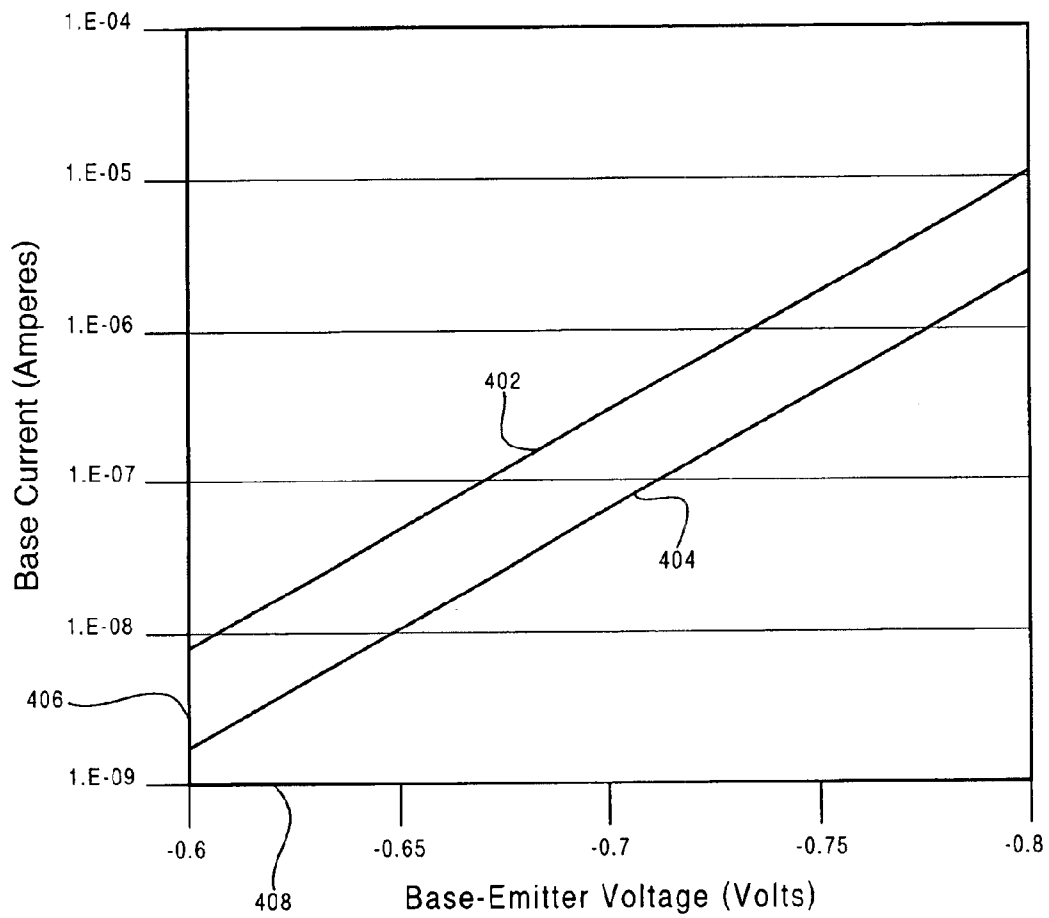


Fig. 4

400 ↙



## HIGH GAIN BIPOLAR TRANSISTOR

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

The present invention generally relates to the field of fabrication of semiconductor devices. More particularly, the present invention relates to the field of fabrication of bipolar transistors.

## 2. Related Art

In addition to high speed, low noise, and high current driver advantages of bipolar transistors, circuits used in modern electronic devices also require low power consumption and high process integration typically provided by metal-oxide semiconductor ("MOS") transistors. In an attempt to combine the benefits of NPN and PNP bipolar transistors with the benefits of MOS transistors, such as P and N channel field effect transistors, semiconductor manufacturers fabricate circuits comprising bipolar and MOS transistors on the same substrate of a die using Bipolar Complementary-Metal-Oxide-Semiconductor ("BiCMOS") technology.

To reduce manufacturing cost, semiconductor manufacturers commonly form lateral PNP transistors such that they are compatible with process flows adapted to fabricate NPN devices or MOS devices. For example, a base of a lateral PNP transistor can be formed utilizing a thin epitaxial N layer that is also utilized to form a collector of an NPN transistor. However, the thin epitaxial layer utilized in the fabrication of a collector of a high performance NPN transistor results in a lateral PNP transistor having an unacceptable gain when the thin epitaxial layer is also utilized to form the base of the lateral PNP transistor. Thus, semiconductor manufacturers are challenged to provide a lateral PNP transistor having an acceptable gain such that the fabrication of the lateral PNP transistor is compatible with the process flow utilized to fabricate an NPN transistor.

FIG. 1 shows a cross-sectional view of a structure that includes a conventional exemplary lateral PNP transistor formed in a manner compatible with a process flow utilized to fabricate an NPN and MOS devices. Structure 100 includes conventional lateral PNP transistor 102, substrate 104, buried layer 106, and silicide layer 108. Conventional lateral PNP transistor 102 includes base 110, emitter 112, and collectors 114 and 116.

As shown in FIG. 1, buried layer 106 comprises N+ type material and is formed in substrate 104 in a manner known in the art. Also shown in FIG. 1, base 110 is situated over buried layer 106 and can be, for example, N type single crystal silicon that may be formed using a dopant diffusion process in a manner known in the art. Emitter 112 is situated over base 110 and may comprise a P+ type material such as P+ type silicon-germanium ("SiGe"), which may be deposited epitaxially in a low-pressure chemical vapor deposition ("LPCVD") process. Further shown in FIG. 1, silicide layer 108 is situated over emitter 112 and provides an ohmic contact for emitter 112 as known in the art. Also shown in FIG. 1, collectors 114 and 116 are formed in substrate 104 in a manner known in the art and can comprise P type material.

The operation of conventional exemplary lateral PNP transistor 102 will now be discussed. When base-emitter junction 118 is forward biased in an active mode of operation, the beta, i.e. the gain, of conventional exemplary lateral PNP transistor 102 is inversely proportional to base

current at constant collector current. Thus, at constant collector current, a decrease in base current will cause the beta to increase. By way of background, base current in a bipolar transistor comprises two dominant components: a space charge recombination current that occurs at depletion region of the base-emitter junction and a diffusion current that is caused by an electron concentration gradient in the emitter of the bipolar transistor.

In the active mode, a high electron concentration exists at the edge of emitter side of base-emitter junction 118 of conventional lateral PNP transistor 102 as a result of forward bias at base-emitter junction 118, among other things. However, at the interface between silicide layer 108 and emitter 112, i.e. interface 120, the electron concentration is approximately zero as a result of the ohmic contact formed by silicide layer 108. Thus, an electron concentration gradient is formed as a result of high electron concentration at base-emitter junction 118 and approximately zero electron concentration at interface 120. The resulting higher electron concentration gradient causes higher electron diffusion current to flow in emitter 112, which increases base current. An increase in base current results in an undesirable decrease in gain, or beta, of conventional exemplary lateral PNP transistor 102, since the gain of lateral PNP transistor 102 is inversely proportional to base current as discussed above. The amount of electron diffusion current flow, and thus the amount of increase in base current, is determined by the steepness of the electron concentration gradient. An increase in steepness of the electron concentration gradient, for example, causes an increase in electron diffusion current.

One approach utilized to increase the gain of a lateral PNP transistor, such as conventional exemplary lateral PNP transistor 102, is to fabricate a thin oxide layer over emitter 112 and then fabricate a polysilicon layer between the thin oxide layer and silicide layer 108. The thin oxide layer functions as an electron barrier that causes an increase in electron concentration at the interface between emitter 112 and the thin oxide layer, which results in a decrease in the steepness of the electron concentration gradient in emitter 112. As a result, base current decreases, which causes the gain of exemplary lateral PNP transistor 102 to increase. However, the above approach results in an undesirable increase in process steps and fabrication cost associated with forming both the thin oxide layer and the polysilicon layer.

Thus, there is a need in the art for a bipolar transistor, such as a lateral PNP bipolar transistor, to have an increased gain without suffering an undesirable increase in process steps and fabrication cost.

## SUMMARY OF THE INVENTION

The present invention is directed to a high gain bipolar transistor. The present invention addresses and resolves the need in the art for a bipolar transistor, such as a lateral PNP bipolar transistor, to have an increased gain without suffering an undesirable increase in process steps and fabrication cost.

According to one exemplary embodiment, a bipolar transistor comprises a base having a top surface. The bipolar transistor might be, for example, a lateral PNP bipolar transistor and the base may comprise, for example, N type single crystal silicon. The bipolar transistor further comprises an emitter having a top surface, where the emitter is situated on the top surface of the base. The emitter may comprise P+ type single crystal silicon-germanium, for example. The bipolar transistor further comprises an electron barrier layer situated directly on the top surface of the

emitter, where the electron barrier layer causes the base current in said base to decrease. The electron barrier layer will thus cause an increase in the gain, or beta, of the bipolar transistor. The electron barrier layer may be a dielectric such as, for example, silicon oxide.

In another embodiment, a floating N+ region, instead of the electron barrier layer, is utilized to increase the gain of the bipolar transistor. Other features and advantages of the present invention will become more readily apparent to those of ordinary skill in the art after reviewing the following detailed description and accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a cross-sectional view of a structure utilized in the fabrication of a conventional exemplary bipolar transistor.

FIG. 2 illustrates a cross-sectional view of an exemplary structure utilized in the fabrication of an exemplary bipolar transistor in accordance with one embodiment of the present invention.

FIG. 3 illustrates a cross-sectional view of an exemplary structure utilized in the fabrication of an exemplary bipolar transistor in accordance with another embodiment of the present invention.

FIG. 4 is a graph comparing the base current in the conventional exemplary bipolar transistor of FIG. 1 to the base current in the bipolar transistors of FIGS. 2 and 3 in accordance with the two exemplary embodiments of the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a high gain bipolar transistor. The following description contains specific information pertaining to the implementation of the present invention. One skilled in the art will recognize that the present invention may be implemented in a manner different from that specifically discussed in the present application. Moreover, some of the specific details of the invention are not discussed in order not to obscure the invention.

The drawings in the present application and their accompanying detailed description are directed to merely exemplary embodiments of the invention. To maintain brevity, other embodiments of the present invention are not specifically described in the present application and are not specifically illustrated by the present drawings.

FIG. 2 shows a cross-sectional view of an exemplary structure that includes an exemplary lateral PNP transistor in accordance with one embodiment of the present invention. Certain details and features have been left out of FIG. 2 that are apparent to a person of ordinary skill in the art. As shown in FIG. 2, structure 200 includes lateral PNP transistor 202, which includes base 204, emitter 206, and collectors 208 and 210. The present invention applies, in general, to any lateral PNP transistor, including a PNP heterojunction bipolar transistor ("HBT"). For example, the present invention applies to lateral PNP HBTs comprising silicon, silicon-germanium, silicon-germanium-carbon, gallium-arsenide, or other materials. However, the present application makes specific reference to a lateral silicon-germanium ("SiGe") PNP bipolar transistor as an aid to describe an embodiment of the present invention.

Also shown in FIG. 2, buried layer 214, which comprises N+ type material, i.e. it is relatively heavily doped N type material, is formed in substrate 212 in a manner known in

the art. Further shown in FIG. 2, sinker regions 216 and 218, which also comprise of N+ type material, can be formed by diffusion of heavily concentrated dopants from the surface of sinker regions 216 and 218 down to buried layer 214. Buried layer 214, along with sinker regions 216 and 218, provide low resistance electrical pathways from base 204 through buried layer 214 and sinker regions 216 and 218 to base contacts (the base contacts are not shown in FIG. 2).

Also shown in FIG. 2, deep trenches 220 and 222 and field oxide regions 224, 226, 228, 230, 232, and 234 may be composed of silicon dioxide and are formed in a manner known in the art. Deep trenches 220 and 222 and field oxide regions 224, 226, 228, 230, 232, and 234 provide electrical isolation from other devices on substrate 212 in a manner known in the art. Although field oxide regions 224, 226, 228, 230, 232, and 234 comprise silicon dioxide in the present embodiment, a person skilled in the art will recognize that other materials may be used, such as silicon nitride, a low-k dielectric, or other suitable dielectric material. Field oxide regions 224, 226, 228, 230, 232, and 234 can also be other forms of isolation, such as shallow trench isolation oxide ("STI"), formed in a manner known in the art.

Further shown in FIG. 2, base 204 is situated above buried layer 214. In the present embodiment, base 204 can comprise N type single crystal silicon, which may be epitaxially deposited using a reduced pressure chemical vapor deposition ("RPCVD"), an LPCVD, or a chemical vapor deposition ("CVD") process. Also shown in FIG. 2, emitter 206 is situated on top surface 236 of base 204. In the present embodiment, emitter 206 can comprise P+ type single crystal SiGe, which may be epitaxially deposited using an RPCVD, LPCVD, or CVD process. Base-emitter junction 238 is formed at the interface between base 204 and emitter 206.

Also shown in FIG. 2, emitter contact layers 240 and 242 are situated over field oxide regions 228 and 230, respectively, and provide low resistance connections to emitter 206. Emitter contact layers 240 and 242 may comprise polycrystalline SiGe, which may be epitaxially deposited in an LPCVD or RPCVD process. Further shown in FIG. 2, electron barrier layer 244 is situated on top surface 248 of emitter 206. In the present embodiment, electron barrier layer 244 can comprise silicon oxide or other dielectric and may be deposited on top surface 248 of emitter 206 utilizing an LPCVD or RPCVD process. In one embodiment, electron barrier layer 244 may be formed over only a portion of top surface 248 of emitter 206. Since electron barrier layer 244 may be fabricated using existing BiCMOS process steps, the fabrication of electron barrier layer 244 does not require additional process steps and additional fabrication cost.

Further shown in FIG. 2, silicide layers 250 and 252 are situated on emitter contact layers 240 and 242, respectively. Silicide layers 250 and 252 provide low resistance ohmic contacts for connecting to emitter 206 via emitter contact layers 240 and 242, respectively. Silicide layers 250 and 252 can comprise, for example, tungsten silicide ("WSi<sub>2</sub>"), titanium silicide ("TiSi<sub>2</sub>"), or other appropriate silicide as known in the art. Also shown in FIG. 2, collectors 208 and 210 can comprise P+ type material, i.e. a heavily doped P type material, and can be formed in silicon substrate 212 in a manner known in the art.

The operation of lateral PNP transistor 202 will now be discussed. In an active mode of operation, where base-emitter junction 238 is forward biased, the gain of lateral PNP transistor 202 is determined by the equation:  $\beta = i_c / i_b$ ,

where “ $\beta$ ” is the gain of lateral PNP transistor **202**, “ $i_c$ ” is the current flowing through collectors **208** and **210**, and “ $i_b$ ” is the current flowing through base **204**. By way of background, the current flowing through base **204**, i.e. “ $i_b$ ,” comprises two dominant components: a space charge recombination current that occurs as a result of base-emitter junction **238** and a diffusion current that is caused by an electron concentration gradient in emitter **206**.

In the active mode, a high electron concentration exists at base-emitter junction **238** as a result of forward bias at base-emitter junction **238**, dopant concentration in emitter **206**, and dopant concentration in base **204**. At the interface between electron barrier layer **244** and emitter **206**, i.e. top surface **248** of emitter **206**, electron barrier layer **244** operates as an electron diffusion barrier, which causes electrons to accumulate at top surface **248** of emitter **206**. However, the electron concentration that accumulates at top surface **248** of emitter **206**, i.e. the interface between emitter **206** and electron barrier layer **244**, is lower than the electron concentration at base-emitter junction **238**. Thus, an electron concentration gradient is formed as a result of the difference in electron concentration between base-emitter junction **238** and top surface **248** of emitter **206**. The steepness of the slope of the electron concentration gradient determines the amount of electron diffusion current that flows into emitter **206**.

In contrast, in a conventional lateral PNP transistor, such as conventional lateral PNP transistor **102** in FIG. **1**, the silicide layer that forms an ohmic contact on the emitter, such as silicide layer **108** in FIG. **1**, causes the electron concentration to be approximately zero at interface between the silicide layer and the emitter. As a result, the slope of the electron concentration gradient in emitter **112** of conventional lateral PNP transistor **102** is much steeper than the slope of the electron concentration gradient in emitter **206**. As a result, the electron diffusion current and, consequently, the base current, are much higher in conventional lateral PNP transistor **102** than in lateral PNP transistor **202**. Thus, the beta, i.e. the gain, of lateral PNP transistor **202** is much higher than the beta of conventional lateral PNP transistor **102**. The beta of the present invention’s lateral PNP transistor **202** can be, for example, between approximately 20.0 and approximately 50.0. In contrast, the beta of a conventional lateral PNP transistor, such as conventional lateral PNP transistor **102** in FIG. **1** can be, for example, approximately 10.0.

Thus, by utilizing electron barrier layer **244** as an electron diffusion barrier to reduce base current, the present invention advantageously achieves a lateral PNP transistor having a beta approximately two to five times higher than a conventional lateral PNP transistor using a silicide layer, i.e. an ohmic contact, over an emitter. Furthermore, the present invention advantageously achieves a much higher beta than a conventional lateral PNP transistor without an undesirable increase in process steps and fabrication cost.

FIG. **3** shows a cross-sectional view of an exemplary structure that includes an exemplary lateral PNP transistor in accordance with one embodiment of the present invention. Certain details and features have been left out of FIG. **3** that are apparent to a person of ordinary skill in the art. In structure **300** in FIG. **3**, base **304**, emitter **306**, collectors **308** and **310**, substrate **312**, buried layer **314**, sinker regions **316** and **318**, deep trenches **320** and **322**, filed oxide regions **324**, **326**, **328**, **330**, **332**, and **334**, top surface **336**, base-emitter junction **338**, emitter contact layers **340** and **342**, top surface **348**, and silicide layers **350** and **352** correspond, respectively, to base **204**, emitter **206**, collectors **208** and

**210**, substrate **212**, buried layer **214**, sinker regions **216** and **218**, deep trenches **220** and **222**, filed oxide regions **224**, **226**, **228**, **230**, **232**, and **234**, top surface **236**, base-emitter junction **238**, emitter contact layers **240** and **242**, top surface **248**, and silicide layers **250** and **252** in structure **200** in FIG. **2**. To preserve brevity, only the differences between the embodiment of the present invention shown in FIG. **3** and the embodiment of the present invention shown in FIG. **2** are discussed below.

As shown in FIG. **3**, floating N+ region **354** is situated on top surface **348** of emitter **306**. Floating N+ region **354** can comprise N+ type polysilicon, which may be formed, for example, by depositing polysilicon and doping the polysilicon with an appropriate dopant while the polysilicon is being deposited in a CVD process. Floating N+ region **354** can be deposited in the same process step as emitter **306** and, as a result, floating N+ region **354** does not require additional process steps and fabrication cost. Floating N+ region **354** is not driven and, as such, the voltage of floating N+ region **354** is unknown. Floating N+ region **354** forms a PN junction at interface **356**, where floating N+ region **354** contacts emitter **306**. In one embodiment, floating N+ region **354** can include a dielectric spacer situated within each of two corner sections of floating N+ region **354**, wherein floating N+ region **354** is situated on emitter **306** such that the dielectric spacers are in contact with top surface **348** of emitter **306**. In such embodiment, the dielectric spacers can comprise silicon oxide or other appropriate dielectric material.

The operation of lateral PNP transistor **302** will now be discussed. Similar to the operation of lateral PNP transistor **202** discussed above, in an active mode, current flowing through base **304** comprises two dominant components: a space charge recombination current that occurs as a result of base-emitter junction **338** and a diffusion current that is caused by an electron concentration gradient in emitter **306**. As discussed above, in the active mode, a high electron concentration exists at base-emitter junction **338** as a result of forward bias at base-emitter junction **338**, dopant concentration in emitter **306**, and dopant concentration in base **304**.

In the active mode, N+ region **354** functions as an electron diffusion barrier to cause a high concentration of electrons to accumulate at interface **356**. However, the electron concentration that accumulates at interface **356** is lower than the electron concentration at base-emitter junction **338**. Thus, an electron concentration gradient is formed in emitter **306** as a result of the difference in electron concentration between base-emitter junction **338** and interface **356**. The steepness of the slope of the electron concentration gradient determines the amount of electron diffusion current that flows into emitter **306**.

Similar to the comparison between lateral PNP transistor **202** and a conventional lateral PNP transistor discussed above, the slope of an electron concentration gradient in the emitter of a conventional lateral PNP transistor is much steeper than the slope of an electron concentration gradient in emitter **306** of lateral PNP transistor **302**. As a result, the electron diffusion current and, consequently, the base current, are much higher in a conventional lateral PNP transistor, such as conventional lateral PNP transistor **102** in FIG. **1**. Thus, similar to lateral PNP transistor **202** in FIG. **2**, the beta, i.e. the gain, of lateral PNP transistor **302** is also much higher than the beta of conventional lateral PNP transistor **102** in FIG. **1**. Similar to the beta achieved by lateral PNP transistor **202**, the beta of lateral PNP transistor **302** can also be between approximately 20.0 and approxi-

mately 50.0, which is much higher than the beta of approximately 10.0 typically achieved by a conventional lateral PNP transistor, such as conventional lateral PNP transistor 102.

Thus, by utilizing floating N+ region 354 as an electron diffusion barrier to reduce base current, the present invention advantageously achieves a lateral PNP transistor having a beta approximately two to five times higher compared to a conventional lateral PNP transistor using a silicide layer, i.e. an ohmic contact, over an emitter. Furthermore, similar to lateral PNP transistor 202 discussed above, the present invention's lateral PNP transistor 302 also advantageously achieves a much higher beta compared to a conventional lateral PNP transistor without suffering an undesirable increase in process steps and fabrication cost.

FIG. 4 shows a graphical comparison of base current in conventional lateral PNP transistor 102 in FIG. 1 versus base current in lateral PNP transistor 202 or 302 in FIGS. 2 and 3 in accordance with two embodiments of the present invention. As shown in graph 400, line 402 represents base current in conventional lateral PNP transistor 102 in FIG. 1 and line 404 represents base current in lateral PNP transistor 202 or 302 of the present invention. Also shown in graph 400, base current axis 406, which shows base current in amperes, is plotted against base-emitter voltage axis 408, which shows base-emitter voltage in volts.

Thus, as shown in graph 400, the present invention's lateral PNP transistors 202 and 302 advantageously achieve a base current that is lower than the base current in conventional lateral PNP transistor 102 by a factor of approximately five. As a result, the various embodiments of the present invention's lateral PNP transistor advantageously achieve a beta that is approximately five times higher compared to the beta achieved in conventional lateral PNP transistor 102.

In one embodiment, instead of utilizing field oxide that is used in lateral PNP transistors 202 and 302 to define the emitter and collector regions, gate oxide formed during fabrication of PMOS transistors can be utilized to define the emitter and collector of the present invention's lateral PNP transistor. In such embodiment, the emitter and collector of the present invention's lateral PNP transistor can be formed by the same implant or diffusion process utilized to form the source and drain of PMOS transistors. In that embodiment, increased beta can be advantageously achieved by utilizing either electron barrier layer 244 as discussed above in lateral PNP transistor 202 in FIG. 2 or by utilizing floating N+ region 354 as discussed above in lateral PNP transistor 302 in FIG. 3.

It is appreciated by the above detailed description that the present invention achieves increased beta in a lateral PNP transistor without requiring additional process steps or increased fabrication cost. From the above description of the invention it is manifest that various techniques can be used for implementing the concepts of the present invention without departing from its scope. Moreover, while the invention has been described with specific reference to certain embodiments, a person of ordinary skills in the art would appreciate that changes can be made in form and detail without departing from the spirit and the scope of the invention. For example, it is appreciated that materials other than SiGe can be utilized in the formation of the invention's

lateral PNP transistor. Thus, the described embodiments are to be considered in all respects as illustrative and not restrictive. It should also be understood that the invention is not limited to the particular embodiments described herein but is capable of many rearrangements, modifications, and substitutions without departing from the scope of the invention.

Thus, a high gain bipolar transistor has been described. What is claimed is:

1. A bipolar transistor comprising:
  - a base having a top surface;
  - an emitter having a top surface, said emitter being situated on said top surface of said base;
  - an electron barrier layer situated directly on said top surface of said emitter in an opening defined by a plurality of emitter contact layers and said top surface of said emitter, said electron barrier layer causing a base current in said base to decrease;
  - wherein said emitter separates said electron barrier layer from said base.
2. The bipolar transistor of claim 1 wherein said bipolar transistor is a PNP bipolar transistor.
3. The bipolar transistor of claim 1 wherein said bipolar transistor is a lateral PNP bipolar transistor.
4. The bipolar transistor of claim 1 wherein said electron barrier layer comprises a dielectric.
5. The bipolar transistor of claim 4 wherein said dielectric comprises silicon oxide.
6. The bipolar transistor of claim 1 wherein said electron barrier layer causes an increase in a beta of said bipolar transistor.
7. The bipolar transistor of claim 1 wherein said base comprises N type single crystal silicon.
8. The bipolar transistor of claim 1 wherein said emitter comprises P+ type single crystal silicon-germanium.
9. A PNP bipolar transistor comprising:
  - a base having a top surface;
  - an emitter having a top surface, said emitter being situated on said top surface of said base;
  - a floating N+ region situated directly on said top surface of said emitter in an opening defined by a plurality of emitter contact layers and said top surface of said emitter, said floating N+ region causing a base current in said base to decrease.
10. The PNP bipolar transistor of claim 9 wherein said PNP bipolar transistor is a lateral PNP bipolar transistor.
11. The PNP bipolar transistor of claim 9 wherein said floating N+ region comprises N+ type polysilicon.
12. The PNP bipolar transistor of claim 9 wherein said floating N+ region causes an increase in a beta of said bipolar transistor.
13. The PNP bipolar transistor of claim 9 wherein said base comprises N type single crystal silicon.
14. The PNP bipolar transistor of claim 9 wherein said emitter comprises P+ type single crystal silicon-germanium.
15. The PNP bipolar transistor of claim 9 wherein said floating N+ region comprises a dielectric spacer situated adjacent to said floating N+ region, said dielectric spacer being in contact with said top surface of said emitter.

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